

The Structure and Dynamics of the Knowledge Networks: Incentives to Innovation and R&D Spillovers in the Brazilian ICT Sector

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Introduction

Tax incentives to innovative activities have been more and more part of the agenda in developing countries. In addition to the traditional arguments about R&D spillovers (Stiglitz, 1989, Arrow, 1962), they have recently also been justified by two set of arguments. The first is related to the formation of absorptive capacity inside local companies, substituting for the lack of usual macro conditions, such as a financial system that supports the long term investments in innovation, and micro requirements, such as an initial level of experienced human resources (Cohen and Levinthal, 1990, Kim, 1995, Shah, 2006, Rodrik, 2002). Second, governments have used tax incentives as a mechanism to attract R&D activities through MNCs under the promise of possible knowledge spillovers derived from the internationalisation of these activities (Grossman and Helpman, 1992, UNCTD, 2005). Governments in emerging economies, reflecting their counterparts in developed ones, have increasingly used tax schemes as a fundamental part of their industrial policy.

However the evidences of the impact and sustainability of these policies are usually inconclusive. Especially in relation to the support to industrial innovation, new methods for analysing the interaction between government, local firms, multinational companies, educational institutions and universities are needed. Using insights from innovation systems, evolutionary economics and organisational learning, recently, studies have taken into account the structure of the longitudinal knowledge-related networks in order to understand the knowledge spillovers in new industries (Malerba, 2002, Owen-Smith and Powell, 2005, Acha and Cusmano, 2005). This paper complements this literature especially in what refers to the formation of the sectoral dynamic in developing countries supported by performance conditioned tax incentives. In specific, this paper investigates the structure and dynamics of the decentralised collaborative arrangements inside innovation projects (henceforth, knowledge networks) induced by tax schemes in the Brazilian ICT sector post liberalisation. The 'ICT Law', as the tax scheme is known, became one of the pioneering projects for the development of sectoral innovation systems in Latin America after its liberalisation policies.

Empirically, this paper aims to contribute with a detailed description of the structure which emerged after liberalisation, the patterns of co-evolution between companies and technological partners and the impact of technological change. This paper draws upon an exclusive dataset containing details of transactions involved in 948 ties formed inside 10088 innovation projects declared under the Brazilian ICT Law between 1997 and 2003. This projects summing up a private investment of more than

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\$2 billion in innovation during the period involving more than 200 companies as well as 200 universities and research institutes. In fact, to the current knowledge of the author, this is the first time that the longitudinal decentralised knowledge network in a developing country is investigated with this level of detailed quantitative data. The database developed in collaboration between SPRU and the Brazilian Ministry for Science and Technology (MCT/SEPIN database) used in this paper is an original empirical basis for the analysis of the characteristics of the sectoral innovation systems in developing countries.

The systemic approach used here is based on three main assumptions. The first is scepticism about the claim that the openness to foreign direct investment will lead inevitably to technological diffusion in regions during the development process. In relation to FDI, the econometric literature had provided controvert evidences in relation to the possible benefits of FDI for the local economy (Hall, 2002, Hall and Reenen, 2000, Xiaoquin Fan, 2002, Tybout, 2002, Saggi, 2000, Reganati, 1997, Kokko and Blomstrom, 1995, Harrison, 1993, Harrison, 1997, Branstetter, 2000). In general, this literature, and its derived policies, tend to neglect cognitive difficulties connected to the transfer of technology, overlooking the complexity of inter-organizational arrangements required (Patel and Pavitt, 1992, Granstrand et al., 1992, Bell and Marin, 2004). Therefore, although integration with the global economy is desirable, there might be points in the development process where understanding the structure of the industrial structure may need to be observed in order to promote the possible required adjustments inside an sustainable technological accumulation process.

Second, we share with others the criticism to the S&T Policy literature, especially in developing countries, that tends to overstate the role of the state formal planning process in the selection of the technologies to be used in hi-tech industries (among others, because usually this analysis is made *ex-post* and mostly in successful cases)(Dodgson, 1989, Lall, 1987, Davies et al., 2001). If we expect to understand the formation of the knowledge systems in developing countries, one must go beyond the analysis and consequent evaluation of the usual nationalistic and politically- charged plans or formal structures and programmes. We must therefore grasp the underlying, more complex process that the set of interactions between private and public economic agents and supporting institutions that define the existence of a system. In this sense, we argue, the literature has paid limited attention to the analysis of the tax incentives as a form of finance that might result in the bottom-up accumulation of technological capabilities inside firms. The increase of the intra-firm technological capabilities is then fundamental to the formation of linkages the decentralised knowledge networks.

Third, specific institutions such as performance-conditioned tax incentives can influence significantly the costs of these investments, therefore the innovative behaviour of the actors (Coase, 1937, Williamson, 1985, Cimoli et al., 2006). In most of the successful catching-up experience, incentives became a premium for those that comply with specific aims of the industrial policy². In fact, many scholars of the late-development literature emphasises the superiority of performance-conditioned

² Throughout the recent years, good proportion of the conditions usually attached to the tax incentives became prohibited under the WTO rules, such as export-performance attached tax incentives and discrimination according to ownership. However, there is still large scope for R&D related incentives.

incentives over indiscriminate incentives (Stiglitz, 1996, Wade, 1990, Teubal, 2000). Naturally, the intervention process should aim the construction of innovation system resembling those of the developed countries, where direct subsidy would be inefficient. However, rather than a clear division between public and private interests, industrial policy and its aims must be understood ultimately as a complex political process given its risky and multi-constituency nature. In addition, if economic and non-economic incentives are to be improved over time, the analysis of the results of the tax incentives must be able to monitor the performance of the organisational arrangements and their effective contribution to the system. Institutional improvement is required to increase efficiency and promote improvements in the complex system of governance that is characteristic of modern catching up process.

The structure of the document is as follows. The first section reviews some studies about the accumulation of technological capabilities in the Brazilian ICT sector and polemic about the impact of the Brazilian ICT Law. The second section discusses the theoretical framework presenting our hypothesis about the operation of the knowledge network. The third section describes the methodology used to test the hypothesis and the characteristics of the database developed. The fourth section contains the results, followed by the conclusions obtained.

1 Perspectives On Innovation In The Brazilian ICT Sector– A Brief Review

Given the increasing cost of the development of new technologies and the stifling impact that the backwardness in ICT had on the overall economy, the protectionist import substitution model ultimately collapsed during the early 1990s. The large number of studies in the Brazilian ICT sector shows that, at the end of this period, the Brazilian ICT sector was characterised by a large backwardness in software, some capabilities in hardware and microelectronics in national firms, and considerable capabilities in telecommunication systems, mainly developed around the powerful CPqD, responsible for most of the technology development during the import substitution phase (Hobday, 1986, Mytelka, 1999, Worden, 1997).

Similar to the other reforms that took place in Latin America in the 1990s, the liberalisation was charged with assumptions that the liberalisation of the market and the inflow of FDI would mean: (i) *a natural source of information and technology for local companies* - an open market, especially in high-tech industries, would be directly related to a greater diffusion of knowledge, therefore, leading invariably to a catching-up process. Endogenous firms would benefit from competition and thrive in the globalised market; (ii) *a reinforcement of existing centres of excellence in research* - private companies were expected to promote higher investments in R&D, while the state would focus on investments in different elements of the system such as universities and research institutes; (iii) *a strengthening of existing clustering activities* – the government was keen to copy experiences supporting entrepreneurship through non-firm organisations, such as technological parks and incubators based on the experiences in the US and Europe. This trend would be reinforced by changes in the multinational strategy towards a decentralised production of knowledge and has resulted in the remerge of an optimistic outlook related to possible ‘knowledge spillovers’.

However, one decade later, the results are quite mixed. The liberalisation process, which involved one of the largest privatisation programmes in the world, undoubtedly has yielded benefits to the modernisation of the infra-structure in Brazil. End-users who struggled in long waiting-lists for expensive fixed and mobile lines enjoy the benefits of competition in the sector. However, the recent studies conducted in the sector point to the impact that the process has had on indigenous capabilities.

In relation to telecommunications, recent evidence point to the considerable disruption in the previous cluster in Campinas organised around the CPqD (Schjolden, 1999, Szapiro and Cassiolato, 2003). The institute was privatised, although an important part of its sustainability remains connected to federal funding. In terms of its core technological capabilities, the previous centre of technological development of the indigenous cluster, the institute was reoriented towards other activities such as their own products, consulting and technological services (Mani, 2004). The dynamic of the sector has shifted towards a dynamic centred on multinational equipment suppliers. However, the patent and publications indicators point to a very low presence or importance of Brazilian subsidiaries in the creation of knowledge inside the multinational companies, although some of them are integrated to global product development networks (Galina and Plonski, 2002).

Software emerged as one of the most promising sectors in Brazil. However, despite some examples, most of the national software firms are still fragmented in dispersed, small companies that lack the characteristics to reach the international market. (Botelho et al., 2003, Arora and Gambardella, 2004). The government created in 1993 an official network of institutes, technological partners and incubators in order to support entrepreneurship and the integration of the industry with the external market, called SOFTEX, based on the experiences in the US. However, according to a detailed analysis provided by Stefanuto, the president of the Brazilian Software Export agency (SOFTEX), the program was never capable of materializing the developmental goal proposed. Despite the lack of results (and investments), it remained the governmental explicit policy measure to the Software Policy of the nineties (Stefanuto, 2004).

Facing these recent studies, the drive for the accumulation of technological capabilities in the ICT industry in Brazil remains unclear. However, common to the study of the software and the telecommunications sector mentioned above is the observation that the tax scheme, called the 'ICT Law'³, is one of the most important aspects in defining the current situation of the sector. However, the similarities in their opinion about the incentives stop there. The studies, even in the same sector, disagree largely on the impact, varying from highly beneficial to the creation of capabilities, to formation of total subservience of the sectoral dynamics to transnational interests.

Recently, some studies have tried to provide a more direct evaluation of the impact of the policy in the sector (Campos and Teixeira, 2004, Garcia, 2002). Their analyses point to the fact that the incentives did not promote the accumulation expected. However, the authors also agree that their evaluation against the first objectives is insufficient, and there is a need to better understand the specific organisational development and the accumulation of capabilities inside the scope of the industrial policy, focusing on the identification of possible adjustments.

Recently, two non-academic conferences have been held in order to assess the impact of the ICT Law in the sector, where companies of different sizes and educational and technological institutes presented the capabilities developed (MCT, 2006, MCT,

³ Although the term ICT Law also was applied to institutional frameworks used during the 1970s and 1980s, most of the authors, and also this paper, use the term in reference to the Law 8248/91 and subsequent adaptations.

2003). These non-academic conferences have provided a rich picture of the diversity of competences emerging in the sector. However, the exact structure and dynamic of this network is not clear for its members and society. In improving the tools to the analysis of this network, this work intends to provide its empirical contribution to this debate.

2 Theoretical Framework - The Structure and Dynamic Of The Knowledge Network

The term network has been widely used as a metaphor to represent the complexity of the innovation process (DeBresson and Amesse, 1991), or a middle of the way between market and hierarchy (Powell, 1990). More recently, the terms sectoral systems and knowledge networks have been an attempt to use new methodological tools for the analysis of the interactions among agents (Malerba, 2005, Wasserman and Faust, 1994, Powell et al., 1996, Pyka and Küppers, 2002). Social network analysis has emerged recently as probably the most promising tool for the analysis of the knowledge flows in different locations.

Given the widespread use of the term to discuss different interactions between actors, the natural first step is the definition of the network under which analysis is bounded. This paper delimits its analysis to the network based on the tax scheme developed in the Brazilian ICT sector, called 'ICT Law'. The tax scheme defined R&D obligations proportional to sales in the national market in exchange to tax exemptions/waves in products of manufacturing companies. In order to be entitled to the tax scheme the companies were obliged to invest approximately 5% of their national turnover in innovative activities⁴.

The nodes of the network are companies and their 'technological partners'. The companies are restricted to national and multinational companies with local manufacturing of products under the incentives (usually products that integrate advanced electronics, such as computers, mobiles and telecommunication equipments). The regulation also defined that part of the investments (approximately 40%) should be conducted with educational and/or technological institutes (henceforth, 'technological partners'), in an explicit attempt to promote university-industry linkages. These partners were especially important in the regulation; therefore they are included as nodes in the network.

The ties of our network are formed by the transactions inside the innovation projects. We focus on the 35000 transactions that involved the collaboration agreements between firms and educational/technological institutes inside the scope of the framework. They formed more than 948 ties among the nodes. Although there were also transactions among companies, the delimitation used here provides a closed network of the organisations under the scope of the tax incentives.

Our definition of the content of the ties is also connected to the activities allowed inside the institutional framework, namely investments in laboratory and infrastructure for S&T, quality systems for R&D, training in S&T, technological services, development of products in hardware, software, semiconductors, systems, production process, as well as research activities

⁴ This percentage has decreased slightly during the last three years of the analysis. See www.mct.gov.br/sepin for more details about the regulatory framework.

Due to obvious constraints, rather than a broad review of the literature about the knowledge networks in its various aspects in political, sociological and economic studies, we will focus on formulating some hypotheses that will help investigate the structure and dynamic of this type of knowledge networks. Three hypotheses are derived from the multi-disciplinary literature on innovation.

For our purpose, in order to understand the flows of knowledge inside the network, we formulate the hypothesis regarding (i) the appropriation of the knowledge, (ii) the knowledge flow among partners and (iii) the impact of technological change. Developing these hypotheses, we expect to provide an insightful framework to explore the structure and dynamic of the knowledge networks in the following section.

One of the most important characteristics of knowledge-based theories is that innovative firms are reluctant in relying on external sources for the development of new products (Granstrand and Sjolander, 1990, Patel and Pavitt, 1998). In fact, external knowledge is complementary, not substitute for internal knowledge (Brusoni et al., 2001)

This is resulted to the fact that although information (i.e. explicit knowledge) can be quite easily transferred instantly through long distances, most of the relevant knowledge is tacit (Kogut and Zander, 1992, Nonaka and Takeuchi, 1995). According to evolutionary economics, rather than widely available in the air, or in regions or countries, knowledge is embedded in people and integrated in organisations through routines⁵. Given the inappropriateness of market transactions in deal with knowledge, firms will tend to integrate vertically their development activities in order to guarantee the appropriation on specific knowledge assets that derive their competitive advantage (Teece, 1988, Prahalad and Hamel, 1990)

Therefore, one must subsequently expect a division of labour in the dyadic relation with technological partners. Firms will prefer to outsource knowledge-related activities that do not confer their comparative advantage, such as technological services and enabling training, that are not related to their core technology, and even research activities, that will just influence the competitive advantage of the firm in the long-run. The first hypothesis therefore explores this basic tenet in the organisation of the knowledge network.

H1- There is a division of innovative labour inside the knowledge network where companies will tend to internalise product development capabilities.

Tacit knowledge, in the form of routines, is not transferred in the economy simply as a result of any economic transactions (Bell and Pavitt, 1993, Nelson and Winter, 1982). The recent empirical literature has pointed to the need to understand the networks by which companies interact in knowledge-related activities in order to understand knowledge spillovers (Bell and Giuliani, 2005, Owen-Smith and Powell, 2005).

⁵ Routines could be defined as executable capabilities for repeated performance in some context that been learned by an organization in response to selective pressures. COHEN, M. D. & AL, E. (1996) Routines and other recurring action patterns of organizations: contemporary research issues. *Industrial & Corporate Change*, 5, 653-98.

Although networks are not the only mechanisms of knowledge spillover⁶, they are increasingly important giving its relatively permanent nature creating a widespread social tissue in the industrial structure where knowledge flow is likely to take place. However, inter-organisational knowledge transfer requires that parties are willing to build knowledge-sharing routines, strengthen their complementary resources/capabilities, and develop effective governance (Dyer and Singh, 1998). Networks in innovative activities (e.g. joint venture, university-industry links, consortia, etc) have become a fundamental way to observe the possible inter-organisational transfer of knowledge (Powell and Smith-Doerr, 1994).

Considering that there is a flow of knowledge that requires different capabilities and governance mechanisms, we should expect a further specialisation happening not just in the relation between companies and partners (as discussed in the previous hypothesis), but in the network as a whole. Specific technological partners will provide specific functions in the process to companies (e.g. general training, joint technological services, R&D activities), and it will determine the type of knowledge that will spill across the partners.

It leads us to the second hypothesis for the operation of the network:

H2 – Routines are not transferred evenly throughout the network. Knowledge (routines) is mostly transferred through specific ties resulting in long-term specialisation in the knowledge network.

The next step in the analysis of the network is the exploration of the impact of technical change. Given the technological trajectory in which the specific industry is embedded (Dosi, 1988, Cimoli and Dosi, 1995), the importance of different actors in the network as well as technological opportunities that they pursue will change over time. On the one hand, the innovation literature points to the bounded rationality of the incumbent firms when facing technical change. This could mean that incumbent companies can be displaced by the new innovative companies using disruptive technologies (Schumpeter and Opie, 1934, Christensen, 1997). On the other hand, studies point out that despite considerable changes in technology; incumbent companies tend to be particularly resilient, taking advantage of scale and scope in their R&D activities (Schumpeter, 1942, Cantwell, 1995). Ultimately, technical change will mean that managers need to adapt and integrate new sources of knowledge technologies, while entrepreneurs identify new opportunities utilizing key resources.

Large companies can create the availability of resources that could be used by entrepreneurs in new opportunities. However, the formation of the network happens when managers need to adapt to technical change and integrate new sources of knowledge, forcing companies not just to compete but also to cooperate in the industrial structure (Cantwell, 2001, Audretsch, 1995). As the complexity of the industrial network grows as different organisations diversify and specialise, technical change will create a need to explore the ‘coordination’ and ‘governance’ of dispersed technological assets in networks (Pavitt, 2001, Prencipe et al., 2003). In other words:

⁶ Other evolutionary mechanisms to transfer tacit knowledge are labour mobility and firm spin-offs.

H3 - Technological change can be disruptive to existing structures, creating opportunities for the emergence of new actors which coordinate dispersed resources as well as integrate ‘old’ and ‘new’ capabilities.

3 Methodology

Despite its central importance, the analysis of the interactions inside innovation systems remains hindered by the poor quality of the available data. This happens mainly due to the complexity of gathering details about the projects and the transactions with different partners, usually conditioned to requirements of confidentiality, as well as the difficulties in coding the different projects in a normalised manner in order to construct databases.

This paper aims to contribute to the literature examining the structure and dynamic of the bottom-up organisational arrangements that have arisen in response to the incentives to innovation activities. Through a collaboration agreement with the Brazilian Ministry for Science and Technology, this relational database was developed based on administrative data collected inside the requirements of the tax incentives developed for the Brazilian ICT manufacturing sector. While keeping the confidentiality requirements of the contract, this research uses the normalised procedure for collecting data from the companies as a way to explore the sectoral dynamic⁷.

In this database of projects, we use some simple variables to explore the principles of the formation of the social network among firms and technological partners discussed in the previous section. Table 1 sums up the hypotheses discussed in the previous section, and is a brief description of the variables and the technique used to analyse the data.

Table 1
Dimensions, Hypothesis and Description of the Variables

Variables	Description	Technique
Knowledge appropriation		
H1- There is a division of innovative labour inside the knowledge network where companies will tend to internalise product development capabilities.		
Type of knowledge-related activity and Vertical Integration	Types of knowledge-related activity allowed inside the framework. Managers classified individual projects among infrastructure to R&D, technological services, training, hardware, system, software, semiconductors, process technology, other types of product development, or research Vertical integration - Two variables were then used for measuring the level of vertical integration in the execution of the projects. (i) Form of governance of the project, distinguished between Make=1, cooperation =0.5, buy=0 (adapted from classification used by managers) (ii) Amount of the costs conducted in internal activities, in contrast to paid to suppliers and partners.	Descriptive statistics and ANOVA test Visualisation techniques
Knowledge transfer		

⁷ Further detail about the database will be provided in the forthcoming thesis.

H2 – Routines are not transferred evenly throughout the network. Knowledge (routines) is mostly transferred through specific ties resulting in long-term specialisation in the knowledge network.		
Central elements and specialisation inside the network	Central elements - Sum of internal activities in the case of companies and sum of ties' strength in the case of partners. Tie strength is measured by the value of the economic transactions between the agents through out the period. The Quadratic Assignment Procedure (QAP) correlation allow the measurement of overlapping partnerships in different networks	Companies Internal R&D and 1 st degree network (Valued) QAP correlation (# of Permutations: 5000, Random seed: 24322)
Technological Opportunities H3 - Technological change can be disruptive to existing structures, creating opportunities for the emergence of new actors which coordinate dispersed resources as well as integrate 'old' and 'new' capabilities.		
Change in Technological capabilities and vertical integration for the different technologies	Trend between proportion of total investments allocated in specific technology and the degree of vertical integration of the innovative activities (Make vs Buy decision)	Trend using two years average

The developed database is limited to the innovation projects executed by companies in the sector presently under the tax regime. Inside these projects, we analyse relations between macro-level (regulation), the projects conducted by agents, (companies and educational/technological institutions), the ties (meso-level structure and dynamics networks) and their content (as discussed before and summarised in Table 2).

Table 2
The Knowledge Network under the Brazilian ICT Law

Delimitation of the innovation network	Description
Institutions	Perform-conditioned Tax incentive - it regulated the investments in innovation in the sector to an minimum of 5% of the national sales, 40% with technological partners
Actors	Firms manufacturing products under the incentives Technological partners - educational and technological institutes
Ties	Collaborative agreements and transactions inside the innovation projects
Content	Type of innovation activities allowed under the incentives

The consolidated data about the network was based on the dataset of the innovative projects developed by companies for the period 1997-2003, declared under the

Brazilian ICT policy⁸. Three datasets were accessed in the Brazilian Ministry for Science and Technology in Brasilia for three different periods under a non disclosure agreement and for academic purposes only. The dataset was cleaned and integrated into the different levels of analysis. The resulting dataset has the following characteristics:

In terms of project, it contains 10,088 projects executed under the Brazilian ICT Law between 1997 and 2003 (an average of 1261 per year). The projects sum up an amount of R\$ 1,618,350,382.66 executed internally to the companies and R\$ 1,114,669,303.82 executed in partnership with universities and technological institutes (annual average of R\$358.1m). We estimated, based on the average cost per employee and the total cost spent on Human Resources, an average of 2355 full-time equivalent engineers/employees per year working inside the incentives (see Table 3 for the consolidated data about the projects).

Table 3
Longitudinal Distribution of the Projects

Total	1997	1998	1999	2000	2001	2002	2003	Average	Total
Investments ("R\$)	304.3	346.8	389.5	560.4	249.6	349.4	306.3	358.1	2864.4
Number of projects	1194	1381	1439	1741	783	1235	1055	1261	10088
Average project size ('R\$)	2421.5	2738.8	2907.5	3868.1	4555.0	4818.0	8799.7	3665.5	33774.1
Equiv. Staff/FT *	2637.2	2823.0	2666.2	3582.1	1535.3	2090.1	1563.6	2355.2	19252.6

* Estimate number of full-time staff (direct + indirect HR costs)/(Average Cost Man/Hour*2000)

In terms of actors, the relational dataset of formal connections involved 216 companies and 235 universities and research institutes inside the Brazilian ICT Law for the period 1997-2003. These actors are located in the entire Brazilian territory with the exception of the Manaus Free-Trade Zone, which receives specific incentives to manufacture and for R&D activities.

In terms of ties, the dataset is formed of more than 35,000 transactions inside the projects, creating 948 ties between these 451 nodes. The organisational data includes the type of organisation (e.g. firms, universities and research institutes), the total investments in innovation, the location and the technology involved in each project. We assume that these data represent 'snapshots' of the formal network that constitutes the 'innovation system' in the Brazilian ICT sector, allowing an estimated proxy for general characteristics of the knowledge networks.

In terms of activities involved in the ties, the network could be divided according to the classification used inside the procedure, namely investments in laboratory and infrastructure for S&T, quality systems for R&D, training in S&T, technological services, development of products in hardware, software, semiconductors, systems, production process, as well as research activities. Table 4 shows the distribution of ties according to type of activities.

Table 4
Ties by Content - Types of Innovative Activity/ Normality test

	Count	Mean	Sum	Table Sum %
Training	240	410,119	98,428,574	9.7%
Services	162	384,709	62,322,833	6.1%
Quality System	120	192,645	23,117,341	2.3%
Infrastructure	174	585,564	101,888,051	10.0%
Process Technology	90	145,265	13,073,880	1.3%
Semiconductors	22	201,092	4,424,023	.4%
Hardware	141	309,055	43,576,789	4.3%
System	230	877,081	201,728,584	19.9%
Software	425	853,509	362,741,319	35.7%
Others	60	154,910	9,294,581	.9%
Research	304	313,994	95,454,311	9.4%

Tests of Normality

		Kolmogorov-Smirnov ^a			Shapiro-Wilk		
KNOW		Statistic	df	Sig.	Statistic	df	Sig.
Semiconductors	Tie Strength (ln)	.096	22	.200*	.973	22	.782
Hardware	Tie Strength (ln)	.045	141	.200*	.995	141	.892
Infrastructure	Tie Strength (ln)	.047	174	.200*	.990	174	.239
Others	Tie Strength (ln)	.100	60	.200*	.974	60	.221
Process Technology	Tie Strength (ln)	.092	90	.056	.946	90	.001
Quality System	Tie Strength (ln)	.065	120	.200*	.986	120	.229
Research	Tie Strength (ln)	.025	304	.200*	.997	304	.847
Services	Tie Strength (ln)	.078	162	.018	.983	162	.043
Software	Tie Strength (ln)	.043	425	.055	.991	425	.010
System	Tie Strength (ln)	.049	230	.200*	.990	230	.094
Training	Tie Strength (ln)	.043	240	.200*	.996	240	.757

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 4 summarises some basic statistics about the network in terms of investments in projects, the number of firms, the number of ties, and the strength and density of the network divided by the different activities.

Table 5
Descriptive Statistics about the 'ICT Law' Knowledge Network - 1997-2003

	Infrastructure	Quality	Technological Services	Training in S&T	Semiconductors	Production Process	Hardware	System	Software	Research
Sum of Investments (" R\$)	169.7	118.2	84.7	159.5	44.7	108.9	203.4	621.7	838.3	121
(with partners)	103.7	27	65.8	100.4	4	13.5	46.3	212.4	385	97.2
Number of firms	142	170	104	177	30	140	191	234	271	195
(with partners)	64	67	76	87	15	44	81	127	157	111
Number of Partners	96	52	71	117	18	54	71	92	140	121
Number of Ties	174	120	162	240	22	90	141	230	425	304
(>R\$ 1M)	18	5	12	20	1	3	8	31	56	23
Tie strength (' R\$) Average	570	174	387	388	189	145	304	799	830	309
Tie strength (' R\$) Maximum	11584	3349	20957	28565	1427	1818	7300	28188	58622	9229
Tie/Total (1/"R\$)	1.02	0.44	2.01	1.62	0.54	0.49	0.69	0.43	0.55	2.6
Density	407	105	258	394	17	53	181	834	1512	381

Finally, before entering the empirical analysis, it is important to the relevance of the regulation in the Brazilian Telecommunications and Computers sector as a whole. One way to proceed is to compare the results with an external measurement of the

total investments in R&D conducted by these two sectors. The total investments in R&D in the telecommunications sector and the computer sector by private companies as assessed by the PINTEC were R\$627m in 2000 and R\$637m in 2003 according to the two innovations surveys conducted in the Brazilian ICT sector (MCT, 2006). In addition, the innovation survey estimated that the total outsourcing of R&D was R\$153.9m in 2000 and R\$184.2m in 2003. From these numbers, it is possible to estimate that the SEPIN database contains in average more than 55% of the investments in innovation projects developed in the sector (the average annual investments inside the ICT Law was R\$386m for the entire period). In addition, more than 85% of the innovation projects outsourced occurred inside the regulatory framework⁹.

Although there are some differences in the concept used to classify R&D in the two databases, the general number obtained through these two different databases show two general remarks about the dataset: (i) There is possibly more R&D activities inside companies in the sector (that contain a much larger sample), although the amount of projects in the dataset is a important proportion. (ii) almost the totality of the outsourced R&D in the computer and telecommunication sector was conducted inside the regulation. Therefore, in general, we assume that the project and ties pointed here do provide an important measurement of the investments that the companies would conduct inside the limits of the sector under analysis.

4 EMPIRICAL RESULTS

In this section, we analyse the hypotheses related to the structure and dynamic of the knowledge network using the case of the Brazilian ICT Law.

H1- There is a division of innovative labour inside the knowledge network where companies will tend to internalise product development capabilities.

The first hypothesis to be analysed is related to the division of labour inside the knowledge networks. Here, we explore the general pattern in the limits in the firm boundary in terms of their Make/Buy decision in different innovative activities. It is important to remember here that, within the institutional framework regulated, approximately half of the total investments should be conducted with technological partners in order to promote linkages with the innovation system.

Table 6 shows the total investments conducted by companies inside the knowledge network and the market created for technological partners in contracts related to innovative activities. (see also Table 9 for the results of the ANOVA test). As expected, our hypothesis that the companies tended to internalise activities related to product and process development was supported. In proportional terms, the development activities were vertically integrated by the company in 84% of the hardware investments, 89% of the production process investments, 92% of the semiconductors, 78% of the system investments and 63% of the software investments.

Other activities not directly related to production were outsourced to partners. Only a smaller part of the investments in infra-structure (46%), technological services (36%), training in S&T (45%) and research activities (22%) were conducted internally.

In Table 6 it is also possible to note some general characteristics of the investments conducted by companies. Clearly, the largest part of the investments went to product development, and more specific to R&D related to software and systems.

⁹ It is supported by anecdotal information that highlights that R&D projects outsourced and the projects under the regulation are usually considered synonyms.

Semiconductors, production, and to lesser extent, hardware, have been smaller sectors.

Particularly in the two large areas of investment, the data implies that there was a considerable market for technological partners which could interact with companies in the development of products. Therefore, they were able to conduct spillovers through the transfer of routines in joint product development activities.

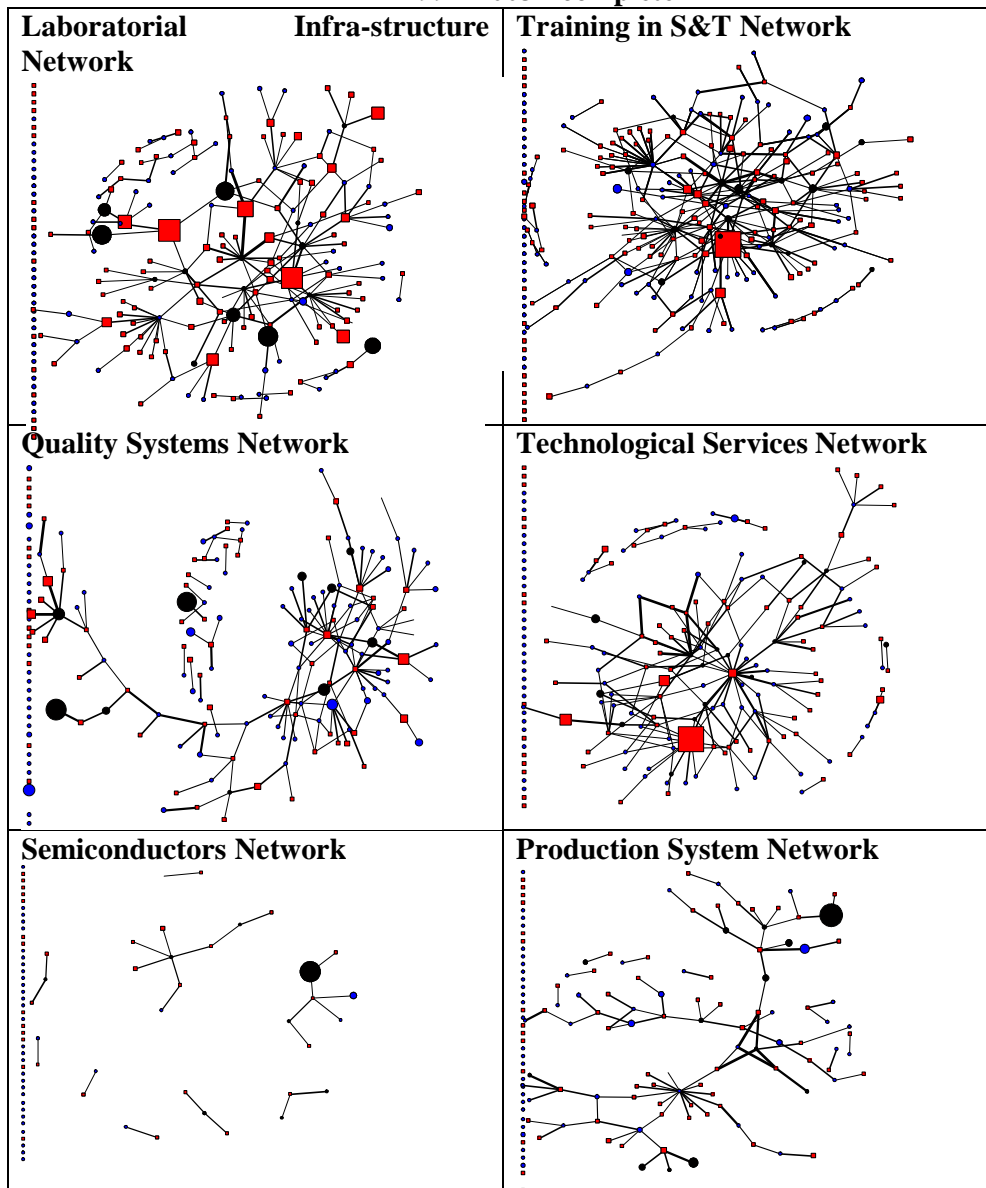
However, as presented in Table 5, the number of ties per total investment is much lower in product development than in training, technological services and research activities. It reinforces the idea that companies have fewer, but strong, ties in product development, while, companies will also tend to have more and weaker ties in relation to technological services, training and research activities.

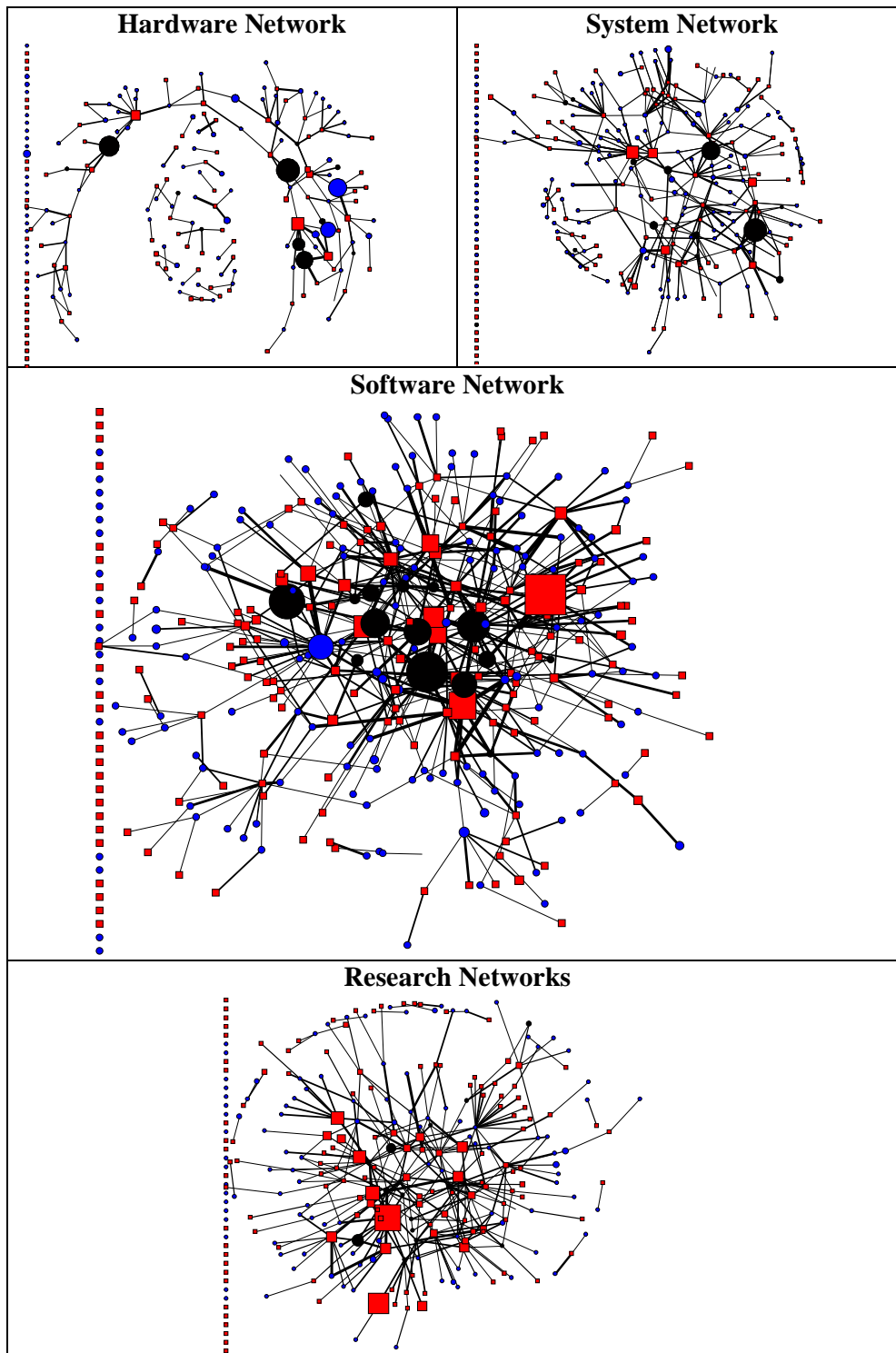
Table 6
Vertical Integration in different Innovative Activities conducted by Companies
under the Brazilian ICT Law. 1997-2003

Vertical Integration			
Trajectory		Internal Costs/Total	Project Governance (Make/Total*)
Infrastructure	Investments		\$184,514,066
	Mean	.43%	.46%
Technological Services	Investments		\$84,745,128
	Mean	.25%	.36%
Training	Investments		\$165,951,781
	Mean	.31%	.45%
Hardware	Investments		\$216,313,457
	Mean	.74%	.84%
Production	Investments		\$108,815,002
	Mean	.78%	.89%
Microcomponents	Investments		\$44,756,985
	Mean	.88%	.92%
Software	Investments		\$842,799,419
	Mean	.48%	.63%
System (HW+SW)	Investments		\$634,740,570
	Mean	.66%	.78%
Others-Dev	Investments		\$34,541,836
	Mean	.63%	.71%
Research	Investments		\$121,107,266
	Mean	.22%	.24%
Total	Investments		\$2,438,285,509
	Mean	.54%	.65%

The Figure 1 provides a visual representation of the division of innovative labour inside the network divided by the different activities. Companies are represented as circles and technological partners as squares. The diameter is proportional to the internal investment conducted during the period. Visual inspection reinforces the argument above about (i) the importance of technological partners in activities such as training, technological services and research, (ii) the incipience of the networks related to semiconductors, production process and hardware, where almost no spillover should be expected, and (iii) the density of the networks related to system and, most of all software, where considerable spillovers could be expected through the technological partners.

Figure 1
The knowledge networks in the Brazilian ICT sector divided by type of activity -
1997-2003 - complete





Source: Based on MCT/SEPIN data using NetDraw 2.37. (Borgatti, 2002)

The Figure 2 presents the same networks, filtered into ties that involved more than R\$1m. It reinforces the results (i) and (ii) above and provides a better glimpse into the key structure of the most dense networks (iii). The analysis of the many clichés in the system network shows that it differs from the structure emerging in the software network. In the system network, capabilities were not consolidated in joint partners as happens in the software network.

Figure 2

The knowledge networks in the Brazilian ICT sector divided by type of Activity - 1997-2003 – Ties stronger than R\$1m.

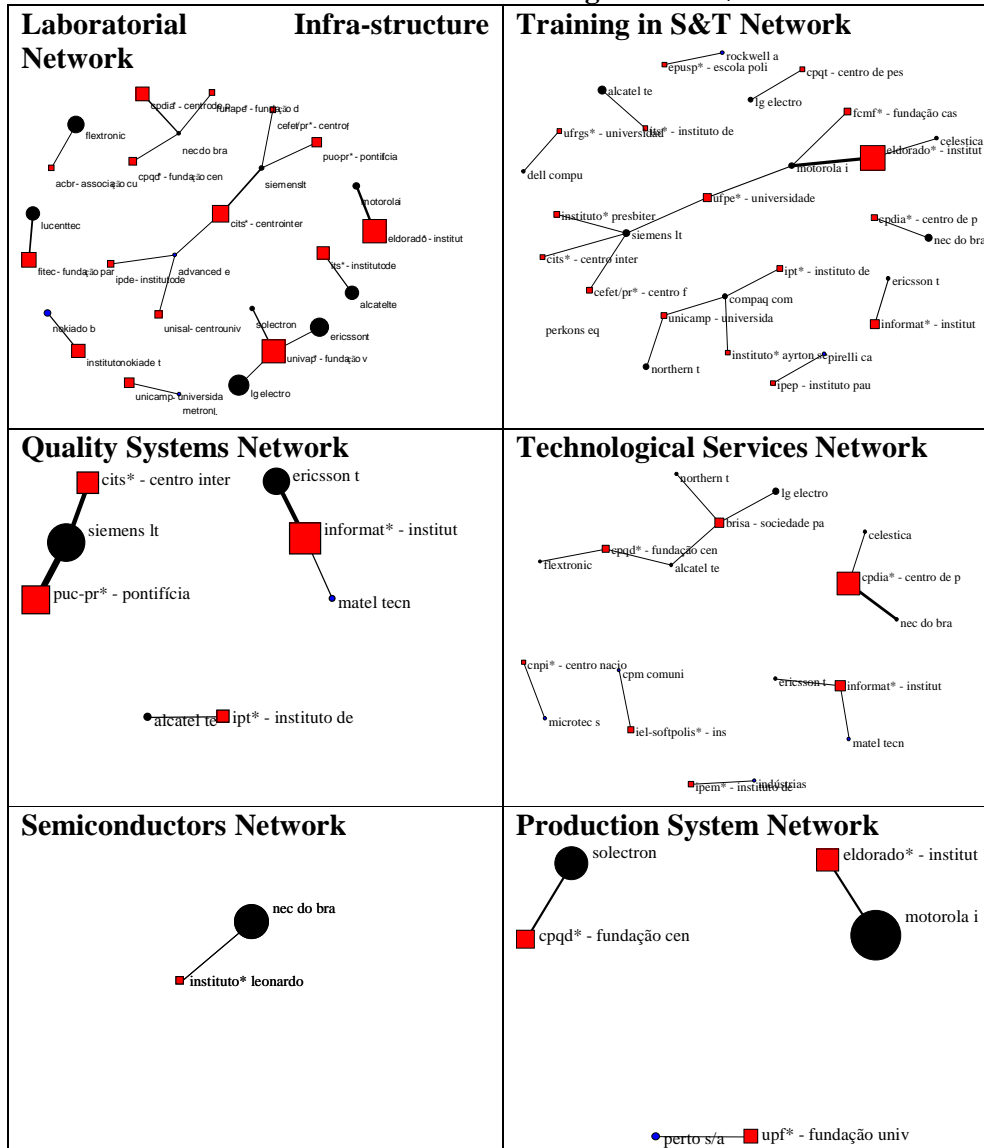


Table 7
Key players in the Different Networks (ranked by locus of implementation of the project)

Rank	Infrastructure	Type	Quality	Type	Technological Services	Type	Training in S&T	Type	Research	Type
1	univap* - fundação v	U	motorola i	MNC	cpdia* - centro de p	PRI	l- eldorado* - institute	PRI	cpqd* - fundação cen	GRI
2	eldorado* - institute	PRI	compaq com	MNC	informat* - institut	PRI	informat* - institut	PRI	cpdia* - centro de p	PRI
3	northern t	MNC	bull tecno	MNC	brisa - sociedade pa	PRI	ufpe* - universidade	U	unicamp - universida	U
4	lg electro	MNC	siemens lt	MNC	cpqd* - fundação cen	GRI	alcatel te	MNC	fitec - fundação par	PRI
5	ericsson t	MNC	nec do bra	MNC	solectron	MNC	nec do bra	MNC	informat* - institut	PRI
6	cits* - centro inter	PRI	microtec s	NC	iel-softpolis* - ins	PRI	nokia do b	MNC	furukawa i	MNC
7	flextronic	MNC(2T)	ibm brasil	MNC	itec s/a	NC	siemens lt	MNC	puc-pr* - pontifícia	U
8	fitec - fundação par	PRI	informat* - institut	PRI	lg electro	MNC	positivo i	NC	puc-rs* - pontifícia	U
9	alcatel te	MNC	puc-pr* - pontifícia	U	dell compu	MNC	lucent tec	MNC	cits* - centro inter	PRI
10	cpdia* - centro de p	PRI	ericsson t	PRI	ipem* - instituto de	GRI	fcmf* - fundação cas	U	cefet/pr* - centro f	U
Rank	Production Process	Type	Hardware	Type	System	Type	Software		Semiconductors	Type
1	compaq com	MNC	nec do bra	MNC	siemens lt	MNC	informat* - institut	PRI	motorola i	MNC
2	pirelli ca	MNC	Motorola I	MNC	nec do bra	MNC	motorola i	MNC	itautech	JV
3	motorola i	MNC	itautech	JV	informat* - institut	PRI	ibm brasil	MNC	instituto* leonardo	PRI
4	solectron	MNC(2T)	siemens lt	MNC	fitec - fundação par	PRI	hewlett pa	MNC	fdte* - fundação par	PRI
5	bull tecno	MNC	cefet/pr* - centro f	U	fmm* - fundação de e	PRI	northern t	MNC	unicamp - universida	U
6	lg electro	MNC	solectron	MNC(2T)	ipt* - instituto de	PRI	cits* - centro inter	PRI	eldorado* - institut	PRI
7	epson paul	MNC	lg electro	MNC	ericsson t	MNC	nec do bra	MNC	siemens lt	MNC
8	celestica	MNC(2T)	fcmf* - fundação cas	PRI	alcatel te	MNC	siemens lt	MNC	ipt* - instituto de	PRI
9	flextronic	MNC(2T)	cits* - centro inter	PRI	ibm brasil	MNC	itautech	JV	autelcom c	NC

10	digicon s/	NC	ica teleco	NC	motorola i	MNC	finatel* - fundação	PRI	cpqd* - fundação cen	GRI
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(U)University (PRI) Private Research Institute (MNC) Multinational Company (MNC 2T) Second Tier Multinational Company (NC) National Company (JV) Joint Venture (GRI) Research Institute with part of its funding linked to the state.

Source: Elaborated with data from MCT/SEPIN. Investments were allocated in the different categories according weights assigned to individual projects.

The first step in the analysis is to identify the type of organisations that have thrived in the different networks. Table 7 shows the most important elements in the knowledge network divided by the type of activity. The analysis supports the previous discussion that Multinational Companies had a key role in the development of innovative activities in most product development activities. There are, however, some other important variations. In some activities, such as process technology, second tier suppliers, have an important role. MNCs were important in developing internal quality programmes.

Most striking, the previous CPqD only had an important role in technological services and research. Universities also have specialised in research activities, rather than in broad participation in product development activities. In these areas of product development, private research institutes became important players.

H2 – Routines are not transferred evenly throughout the network. Knowledge (routines) is mostly transferred through specific ties resulting in long-term specialisation in the knowledge network.

A next step is to expand the analysis from the simply bilateral relation in terms of vertical integration, to the analysis of the division of innovative labour in the network. In order to understand how the process of specialisation happens inside the network, Table 8 shows the result of correlation among the different networks presented above. By doing so, it is possible to observe patterns of specialisation in the different ties, identifying how knowledge is transferred (or unevenly distributed) through ties in the network.

Table 8
QAP Correlation among the Knowledge Networks Developed in Different Activities

	1	2	3	4	5	6	7	8	9	10	11
1- Infrastructure											
2 - Technological Services	0.283										
3 – Training	0.580	0.173									
4 - Quality Systems	0.276	0.197	0.204								
5 – Semiconductors	0.035	0.064	0.033	0.057							
6 - Production technology	0.403	0.132	0.606	0.181	0.081						
7 – Hardware	0.155	0.035	0.101	0.207	0.097	0.217					
8 – System	0.262	0.210	0.265	0.416	0.049	0.145	0.137				
9 – Software	0.309	0.330	0.449	0.577	0.047	0.274	0.158	0.600			
10 – Others	0.473	0.034	0.392	0.410	0.012	0.274	0.314	0.173	0.319		
11 – Research	0.334	0.617	0.183	0.358	0.209	0.181	0.242	0.293	0.368	0.217	

**All the correlations are significant at 0.01.*

QAP procedure developed in UCINET 6(Borgatti et al., 2002)

Analysing the results, five strong patterns of specialisation emerge in the interrelation among the different networks:

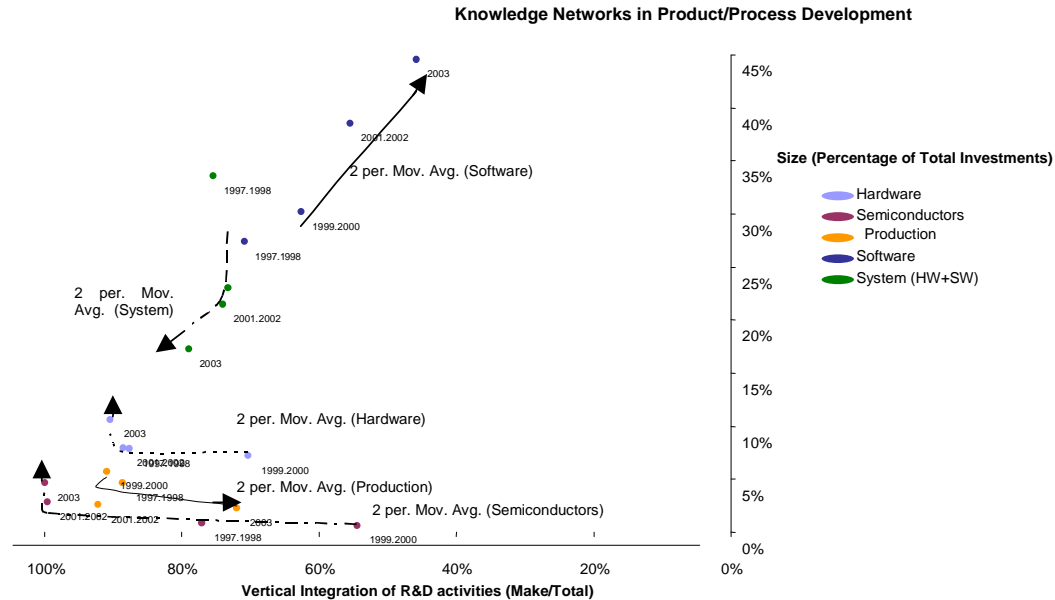
- (i) Training and Infrastructure – The analysis suggests companies used the incentives to improve the infra-structure of partners which could also provide training in new technologies.
- (ii) Training and Production Technology– Production Technology was specially related to training in new technologies.
- (iii) Research and Technological Services – Other partners, became specialised in providing research and technological services (metrology) for the companies. It is interesting to note that, in general, research and technological services (possibly centres of excellence in different

- technologies) were not strongly related with the linkages involved in product and process development.
- (iv) Software and Quality Systems, the improvement of quality systems in R&D (related to certification such as CMM).
 - (v) Software and System. Here, it is possible to speculate about the strong relation between the formation of the capabilities in system and software. Although this test does not allow us to attribute causality, the dynamic process of the interrelation between these networks will be discussed further. Software also has an important, but relatively weaker relationship with new investments in infra-structure, training and research. It is possible to speculate here that there is a 'systemic' sectoral system in software, and not in systems.

H3 - Technological change is disruptive to existing structures, creating opportunities for the emergence of new actors which coordinate dispersed resources as well as integrate 'old' and 'new' capabilities.

As discussed so far, private research institutes have become a fundamental part of the system and software-related network. However, why did this happen? In order to explore the dynamic of the formation and interaction among the knowledge networks, Figure 3 shows the trends in the accumulation of technological capabilities in the different technologies (represented by the percentage of the total investments) and the degree of vertical integration of the innovative activities (represented by the number of projects controlled by the company compared to those outsourced).

Figure 3
Knowledge Networks in Product Development



The strength of the first three arrows in the bottom left reinforces visually that the threshold for a dynamic network has probably not yet been reached. This also shows very different details about the general tendency. The arrows related to semiconductors show incipient, but increasing, initiatives to accumulate technological capabilities inside the companies. An opposite trend is observed in relation to production technology that has decreased and outsourced activities. The arrow and the dots related to hardware show that there is an upward movement, although it has

been turbulent through the period (probably given the instability in the initiatives undertaken by different companies in this type of technology). An important aspect of these three arrows is the strong internalisation of the technological investments inside the firms that could be attributed to the use of non-local linkages (such as intra-firm networks in the case of MNCs or international partners) as the source of technology during these first phases. In this sense, local partnerships with research institutes and universities do not seem to be the source of the technology.

A different portrait can be developed around the dynamic happening in the two largest networks. In fact, they point to opposite directions. While the first three networks are reasonably independent (as highlighted by the correlations), these opposite networks must be understood in terms of technical change (given the strength of the correlation among them). From this trend and previous results, we can imply that the established and newcomer companies have shifted their investments from system to software. While the divestments in systems technology were happening, companies tended to retain internal projects, rather than consolidate. At the same time, the companies which were increasing their investments in software identified existing capabilities available in partners and integrated them in the formation of the knowledge networks in software. This dynamic provided opportunities for private research institutes to diversify the number of partnerships making use of existing knowledge to respond to these new needs. This suggested dynamic is reinforced by the structure of the networks presented in Figure 2.

5 Conclusions

The understanding of the roles of different agents and their knowledge-related interactions has been the key challenge for innovation management and policy. This paper contributed to the empirical literature about sectoral innovation systems exploring the underlying structure and dynamics of the knowledge network developed by the perform-conditioned tax incentives in the Brazilian ICT sector. After the liberalisation, foreign direct investment and tax incentives, the organisation of the existing capabilities in the sector have been unclear and controvert. From the empirical perspective, the paper sheds new light upon the structure that emerged in result of institutional and technological changes in Brazil during the period.

First, the development of the software knowledge-network in Brazil cannot be considered direct result from the liberalisation as it was not sufficient to support the technological dynamic in the sector as the companies outside the regulatory framework. The organisation of the sector was also not designed by a top-down approach either, as evolutionary bottom-up principles were key determinants in the formation of the network. While the tax scheme promoted a higher level of investments in innovation, it did not determine the direction of the innovations occurring in the sector. This paper uses statistical tests and social network analysis to identify some principles for the operation of this knowledge networks in terms of appropriation of the knowledge in different activities of the innovation process, the patterns of the co-evolution of the firms and technological partners, and the trajectory emerging in the different networks.

The first hypothesis stated the principle that external knowledge is complementary to, not a substitute for internal knowledge. Rather than subcontracting strategic activities that would support the capabilities that existed in previous public research centres and universities, companies had important internal initiatives to accumulate product development capabilities. Multinational equipment manufacturing companies became

key players in the accumulation of technological capabilities in the Brazilian ICT sector post-liberalisation in all the different technologies. Knowledge networks emerged supported and constrained by the institutional framework created in the sector and as a result of the decentralised changes in the perception about the technological opportunities. These networks were especially large in relation to system and software technologies.

Second, the paper observed that the routines were not transferred evenly throughout the network. Partnerships specialise in specific parts of the innovation process reinforcing a division of innovative labour. In specific, product development activities in system and software were not connected with the same partners used for training, technological services and/or research. These, in fact, allowed the emergence/growth of private research institutes in the sector. The reasons that made the companies in the ICT sector shift their investments in product development away from existing technological centres and universities are not yet clear. At this moment, it is possible to speculate that this might be the result of the competition for technological resources with previous local companies which crowd out foreign companies and/or a result of differences in terms of appropriability strategy. Certainly there might be others aspects such as costs and flexibility that may also help explaining this behaviour.

Third, it was possible to observe that technological change was disruptive to existing structures, at the same time creating opportunities for the emergence of new actors. The technological opportunities identified by the companies have changed considerably during the period. Clearly companies inside the framework identified limited opportunities in microelectronics, hardware and production process. At the same time, there was also a significant change from opportunities in system to software technologies. The change can be inherited to the dynamic of the industry, but it may also be related to the development of complementary technological role of the subsidiary inside the multinational division of labour. Important here is that as result of this change, new private research institutes emerged as key elements in the software knowledge network. They were a relative small number of technological partners involved in product development for large multinational companies in system-related product development. However, as the investments changed from system to software, private research institutes emerged as important network integrators in the promising software-related knowledge network in Brazil.

A important aspect to be considered in more detail is to role of the subsidiary development and the characteristics of these private research institutes that emerged in the software knowledge network. Further analysis of the role played by the technological leadership of the multinational companies in the different networks, and the integration with external sources of knowledge will be the focus of further research. In addition, the private research institutes are certainly a fascinating spillover of the institutional framework, with implications for the forthcoming dynamics. Following an evolutionary perspective, they constitute a hybrid of valuable routines developed in partnerships with large and small companies with a regulatory commitment to promoting the diffusion of knowledge in the system. Although the diffusion of knowledge beyond the initial partners do not necessarily occur for cognitive and/or strategic reasons, these vertically disintegrated technological networks retained capabilities that are certainly important for entrepreneurial companies into new ventures. These organisations are important spaces where companies can explore complementarities and coordinate disperse capabilities.

However, the extent to which these organisations operate as private organisations or policy networks is certainly a question that needs to be investigated in detail.

In addition, although we started analysing some basic assumptions about the operation of the knowledge network, the exploration of the relation between the type of institutions and the organisation of these decentralised knowledge networks still remains in its infancy. This research raises lines of theoretical and policy enquiry that remain largely open. For instance, how do individual actors contribute to the vitality of these networks? How could changes in the rules promote a better allocation of resources in the decentralised network? Which kind of interventions (or non-interventions) should be carried out in different stages of the development of the knowledge networks? Which mechanisms should be combined in order to promote larger knowledge spillovers, stronger growth and sustainability in the networks? Further detailed analysis of the cognitive aspects of these networks as well as the developments in methodological tools need to be considered in order to attempt some answers to these questions.

Finally, in addition to the questions related to knowledge and learning, the research provides a glimpse on how the institutional framework can provide the space for the interaction between different economic agents which have very different interests. The formation of this social capital seems to be the basis for compromise and adjustment, and the identification of endogenous growth opportunities. Although different organisations have come a long way since the import-substitution era, there is still a long way ahead. In many technologies, the accumulation has been limited, and, to a large extent, the future of the software industry in Brazil is still not written. Considering the challenges ahead, there are many lessons to be extracted from this experience by government, companies and technological institutes in the enterprise of promoting sectoral innovation systems in the post-liberalisation era in Latin America.

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